BBC RD 1989/11

Research Development Report

PREDICTION OF VHF/UHF MOBILE RECEPTION IN URBAN AREAS:

Comparison with measurements in London

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Summary

The BBC's interest in mobile reception stems from its Ancillary Service requirements at VHF and UHF and also the increasing use of the VHF-FM band for broadcast reception in cars. This has stimulated interest in predicting field strengths for mobile reception at both VHF and UHF.

This Report describes the results of high density field strength measurements in the London area using a receiving antenna height of 1.4 m. Comparisons are made with predictions using a modified version of the long-established BBC method originally developed for predicting interference levels at a 10 m receiving antenna height. To date, these comparisons show good agreement.

Issued under the Authority of

Head of Research Department

Research Department,
BRITISH BROADCASTING CORPORATION

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PREDICTION OF VHF/UHF MOBILE RECEPTION IN URBAN AREAS: COMPARISON WITH MEASUREMENTS IN LONDON

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1. INTRODUCTION

Interest in mobile reception for both broadcast and communications purposes, particularly in urban areas, has prompted an investigation into ways of modifying the existing BBC field strength prediction programs[1] to enable the prediction of coverage information for these lower antenna height services. This Report describes the results, comparing predictions with data collected in the London area, which were originally reported at ICAP '87[2].

2. BBC PREDICTION PROGRAM HISTORY

The BBC uses computer-based field strength prediction methods to assist with the planning and development of its UHF television and VHF radio services[1]. The basic method was developed about 20 years ago for UHF television and involves the use of a terrain databank to generate a path profile between the transmitter and receiver. Various path loss calculations are carried out according to how this profile reacts with a straight line drawn between the transmitter and receiver. The method was optimised for a receiving antenna height of 10 m, this being the typical height of a domestic installation.

Later, a similar method was developed for use at VHF frequencies which has much in common with the UHF method, the profile generation being independent of frequency. However the propagation mechanisms have a different emphasis and the path loss calculations have been modified.

It is important to realise that these prediction programs are normally used for interference calculations to indicate when a particular frequency can be re-used without introducing co-channel or adjacent channel problems. The assessment is in terms of the field strength exceeded for 1%, 5% and 50% of time and for 50% of locations, since this is more relevant to the planner's needs than the fundamental path loss. Considering the present density of spectrum re-use in the UK television and radio transmitter networks and the relative lack of co-channel interference problems, the method has proved highly satisfactory for the purposes for which it was designed.

However, these programs have limited application for broadcast service area prediction (by calculating the field strength at specific points) due to the statistical nature of the result. Nevertheless, at the lower antenna heights applicable to mobile reception, field strength at VHF and UHF varies considerably with location and can only be usefully defined in statistical terms. Therefore it is reasonable to suppose that these programs may also be suited to the prediction of mobile coverage areas, once account of the antenna height differences has been made.

The program is extremely complicated due to the many propagation effects, which over a long distance path, need to be accounted for in a field strength prediction model. Calculations are made for knife edge diffraction, spherical surface diffraction and wedge diffraction. Also calculated are free-space loss, clutter loss, duct loss and scatter loss. These are derived from frequency, distance and terrain information, the latter being taken from a terrain databank. For mobile service area prediction, where the paths will tend to be relatively short and over land, some of these calculations are not used; duct and scatter loss for instance. Others such as clutter loss and the diffraction calculations may require modification and re-optimisation to take account of the different environment at low receiving antenna heights.

To investigate the effectiveness of the programs it is necessary to collect a great deal of information about how the signal received by a moving vehicle varies at VHF and UHF in various types of terrain and topography. Computer-based data-logging techniques make this type of work relatively easy and it then becomes possible to make comparisons between measurements and predictions for the same area.

3. THE MEASUREMENT WORK

The work so far has been concentrated in London where approximately 260 km of road have been surveyed (equivalent to 260,000 measurements). Specific areas were chosen, in central and south London, to represent various classifications of clutter, namely rural, sub-urban, urban and dense urban. Path distances vary between 5 and 15 km. These areas were divided into ½ km × ½ km squares for convenience and the field strength variation in each square, at low antenna height, was measured in a moving vehicle. The results of this work, when compared to the appropriate predictions would enable us to decide whether effective mobile service area predictions can be achieved by predicting directly to the lower antenna height.

The mobile survey vehicle was an ordinary saloon car, fitted with a quarter-wave whip antenna in the centre of its roof which was nominally 1.4 m above ground level. This fed a field strength measuring receiver and data-logging equipment. The object was to cover as many roads as possible in each square, sampling the received signal at 1 m intervals. The resulting data was stored on magnetic disc for subsequent statistical analysis on a microcomputer, the output being in the form of three field strength values for each square, namely the levels exceeded for 10%, 50% and 90% locations.

The transmitter was located at BBC Television Centre, in west London, with the antenna mounted on the roof of a nine-storey building 57 m above ground level. To date, measurements have been made at 104, 141 and 469 MHz from this location using vertical polarisation. Although such a site is typical of many urban transmitters, there are cases where antennas are mounted on high masts, well clear of local clutter. To simulate this, further measurements are being carried out on transmissions from the mast at Crystal Palace, the London television transmitter site.

4. COMPARISON BETWEEN MEASUREMENTS

Since the three transmissions from Television Centre all have the same effective radiated power (e.r.p.) and antenna height it is interesting to compare the relative differences in field strength at each frequency.

Fig. 1 shows the cumulative field strength distributions for all the ½ × ½ km squares at the three frequencies and represent about 260,000 samples at each frequency. The data has been normalised to an e.r.p. of 25 watts. Table 1 gives the standard deviations relating to these three sets of measurements.

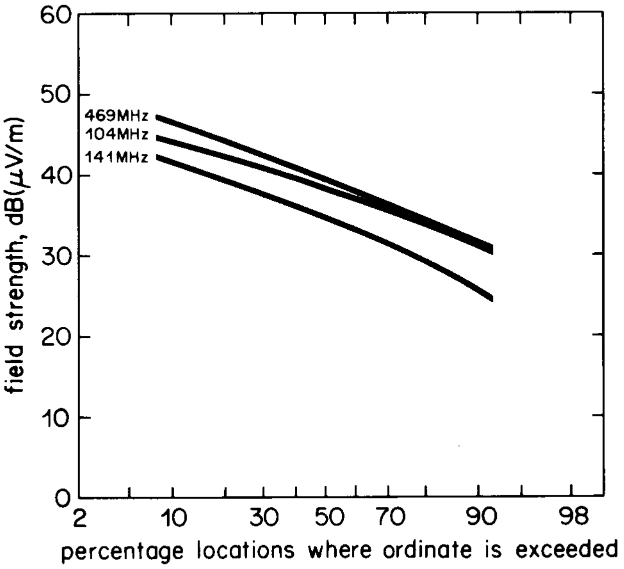


Fig. 1 - Distribution of measured field strength at 104, 141 and 469 MHz.

Table 1
Standard deviations of measurements shown in Fig. 1

Frequency (MHz)	Standard deviation (dB)
104	5.1
141	6.3
469	5.9

All three distributions show the expected log-normal characteristic although, at the 50% level, there is a difference of 4.6 dB between the 469 and 141 MHz measurements with the 104 MHz results lying between them.

The 104 and 141 MHz measurements were made some six months after the 469 MHz set, although the route taken in each square was adhered to as far as possible. Any changes which did occur, due for instance to road-works, were very minor and unlikely to significantly affect the 50% location value for a square. Similarly, propagation differences are unlikely to be very large over this frequency range, particularly between the two lower frequency sets.

This leaves antenna calibration as the major remaining source of error. Determination of exact antenna gain at these frequencies is notoriously difficult due to the presence of extraneous reflected signals. A range of ±1 dB is the normally accepted level of uncertainty when calibrating such an antenna system. Since two antennas (transmit and receive) for each of the three frequencies are involved it is easy to see how the differences shown in Fig. 1 can arise. These variations need to be remembered when comparing measurements with predictions.

5. CLUTTER CATEGORISATION

In order to assess the effects of clutter on the received signal an attempt was made to classify the area in which measurements were being made. It proved possible to identify (with reasonable repeatability between different operators) four different types of clutter. These are as follows.

Rural:	Open country with few buildings or trees.
Sub-urban:	Residential areas with predominantly two-storey buildings.

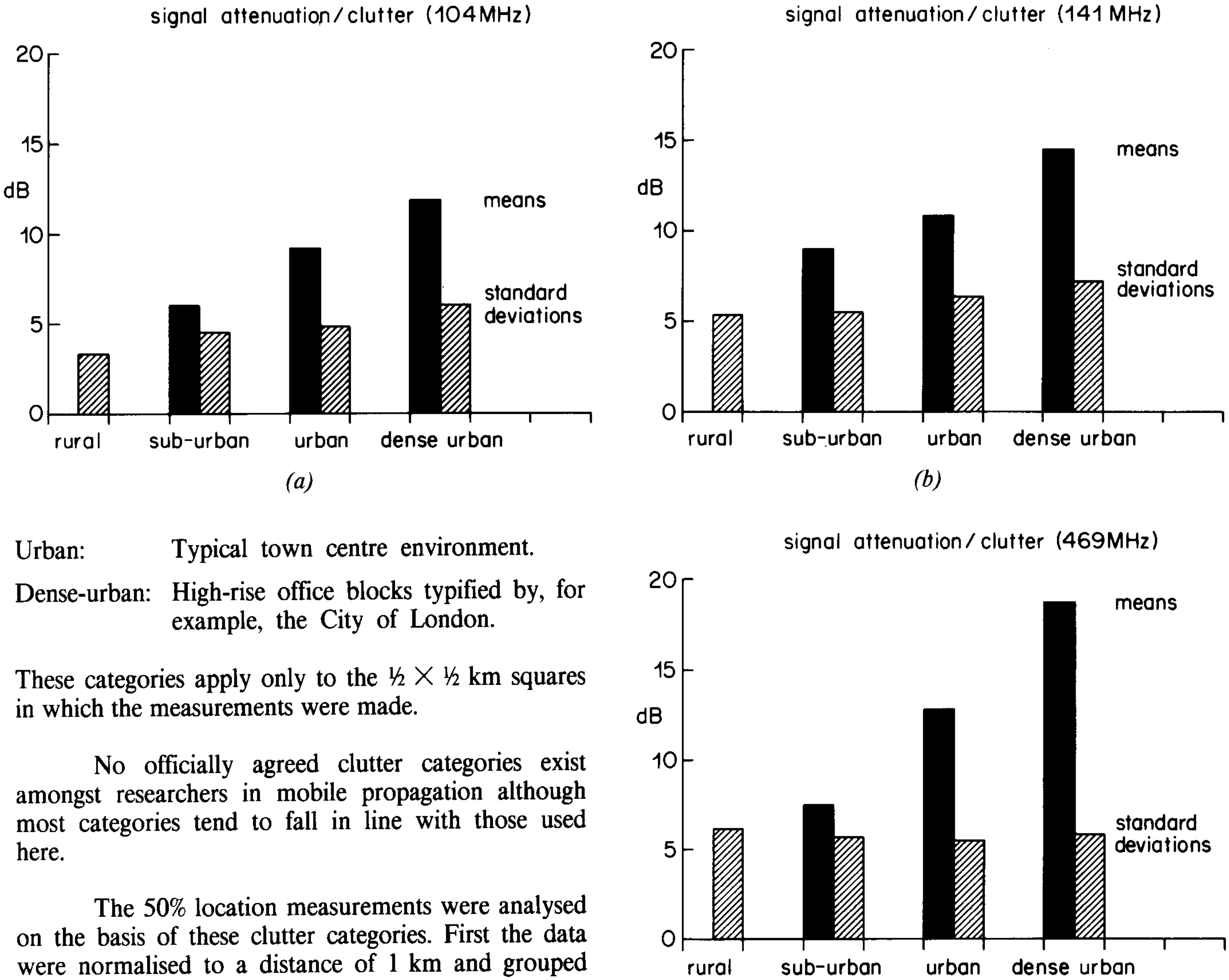
Urban: Typical town centre environment.

Dense-urban: High-rise office blocks typified by, for example, the City of London.

These categories apply only to the ½ × ½ km squares in which the measurements were made.

No officially agreed clutter categories exist amongst researchers in mobile propagation although most categories tend to fall in line with those used here.

The 50% location measurements were analysed on the basis of these clutter categories. First the data were normalised to a distance of 1 km and grouped into the respective clutter categories for each of the three frequencies. Then the mean and standard deviation was found for each clutter category. To compare the mean values at the three frequencies the effects of calibration uncertainty were removed by referring everything to the Rural category. Then, rather than dealing in terms of absolute field strength, the effects of clutter can be seen as signal attenuation relative to the Rural values. This was not necessary when comparing the standard deviations.



(a) *(b)* *(c)*

Fig. 2 - Means and standard deviations of the normalised 50% location field strength measurements analysed in terms of rural, sub-urban, urban and dense-urban clutter.

(a) at 104 MHz (b) at 141 MHz (c) at 469 MHz

Fig. 2 (a, b and c) and Table 2 show the results. It can be seen that as clutter increases, i.e. going from Rural to Dense Urban, the mean signal

Table 2: The effect of clutter on signal strength
(Mean signal attenuation, relative to Rural category and standard deviation)

Clutter category	104 MHz		141 MHz		469 MHz	
	Mean (dB)	s.d. (dB)	Mean (dB)	s.d. (dB)	Mean (dB)	s.d. (dB)
Rural	0.0	3.4	0.0	5.3	0.0	6.2
Sub-urban	6.0	4.5	9.1	5.6	7.6	5.8
Urban	9.2	5.0	10.9	6.5	13.0	5.6
Dense Urban	12.0	6.1	14.6	7.3	18.9	5.9

attenuation increases significantly whereas the standard deviation remains reasonably the same.

The fact that the attenuating effect of clutter increases with frequency has been reported elsewhere[3]. The same reference also notes that standard deviation is sensitive to the size of the measurement area, which implies that, if the measurement areas are all of the same size, the standard deviation will tend to show little variation. This is confirmed by the BBC measurements which were made in squares of constant size (½ × ½ km) and result in standard deviations having relatively little variation with respect to clutter or frequency.

6. PREDICTION WORK AT VHF AND UHF

Field strength predictions were carried out to the centre of each ½ × ½ km square for a 1.4 m receiving antenna height. The 50% time, 50% location predicted results were compared with the 50% location measured values, all field strengths being normalised to an e.r.p. of 25 watts.

Initially the UHF version of the prediction program was used for the 469 MHz predictions and the VHF version for the 141 and 104 MHz predictions. However it soon became apparent that the VHF program was predicting some 15 dB higher than the measured field strengths, irrespective of clutter category, whereas the UHF version was much closer to the corresponding 469 MHz measurements[4].

This was found to be due to differences in the way that the two programs calculate diffraction loss and clutter loss. Where signal diffraction occurs the VHF program interpolates between knife-edge and wedge loss to determine the effective loss, whereas the UHF program simply uses the wedge loss as calculated, which is always higher. The clutter loss in both programs is related to a zone-filling parameter. However in the VHF program this loss limits at about 12 dB whilst in the UHF program it is allowed to rise linearly to a maximum value of 26 dB.

Hence the overall path loss calculated by the UHF program will tend to be higher than that calculated by the VHF version.

Two versions of the same program originally arose through the need to obtain best fits with measured data in two specific broadcast frequency bands (VHF and UHF) relating to a 10 m receiving antenna height and including potentially interfering long-distance propagation situations. Consequently when used for different applications, such as low antenna height mobile prediction over relatively short distances, one should not necessarily expect either version of the model to provide good results. The fact that the UHF version appears to work quite well may just be coincidental to the measurement data set (London area) and in other areas, perhaps with a higher transmitting antenna, the correlation may not be so good.

Nevertheless, in the following analysis, as a basis for further development, the UHF version has been used at 104 and 141 MHz as well as at 469 MHz.

7. COMPARISON BETWEEN PREDICTIONS AND MEASUREMENTS

The measured and predicted field strengths for a 1.4 m receiving antenna height at the three frequencies are compared in Fig. 3 (a, b and c) which also show the regression lines. Table 3 gives the associated mean differences (prediction–measurement), standard deviations and correlation coefficients.

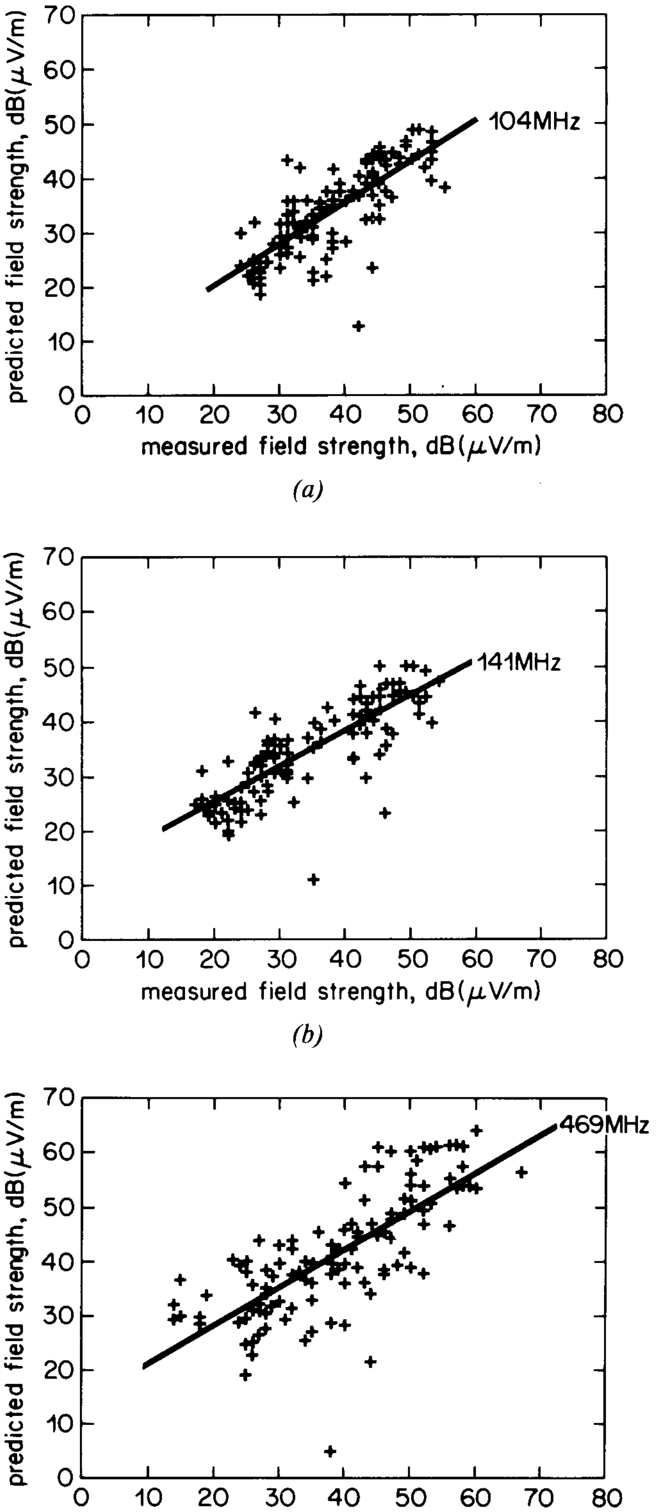
Table 3
Difference between predictions and measurements

Frequency (MHz)	Mean difference (dB)	Standard deviation (dB)	Correlation coefficient
104	−4.1	5.5	0.8
141	0.7	6.2	0.8
469	2.7	8.6	0.7

Bearing in mind the accuracy limitations inherent in the measurements (see Section 4) and the fact that the prediction program is the UHF version, this comparison shows good agreement with the predictions at VHF as well as at UHF. The mean differences and standard deviations are similar to, and in some cases better than those obtained by other prediction methods[5,6,7], including those using three-dimensional GTD techniques[8].

8. PERCENTAGE LOCATION VARIATION

With mobile communication it is sometimes necessary to have at least 90% location coverage, for instance when program links are involved, and the prediction method should take this into account. As mentioned in Section 3, the low antenna height survey data is analysed to give 10%, 50% and 90% location values and from Fig. 1 the difference between the 50% and 90% values for the three frequencies varies between 7 and 10 dB, the average being 8 dB. No frequency-dependent trends can be identified.



(a)

(b)

(c)

Fig. 3 - Comparison between predictions (UHF program) and measurements.

(a) at 104 MHz (b) at 141 MHz (c) at 469 MHz

The analysis has shown that the predictions agree reasonably well with the 50% location measurements. Therefore a predicted 90% coverage contour could be obtained simply by predicting a level which is 8 dB higher than the usual 50% location contour.

So far, this 8 dB factor only applies in London since other representative areas have yet to be investigated. However analysis of the data shows that it is fairly independent of the clutter category and so may be equally applicable in other areas.

9. EFFECT OF BASE STATION LOCATION

It is perhaps worth noting that, from experience gained in the planning of the Band II radio service, the reception of VHF transmissions from high sites can be impaired by signal cancellation over a wide area if the transmitting antenna height, in conjuction with a suitable foreground reflection point, happens to provide the necessary phase difference. This difficulty can normally be overcome by moving the transmitting antenna vertically until the problem disappears, but it is necessary to bear it in mind when planning VHF transmitters, since it is virtually impossible to predict without very detailed knowledge of the terrain and clutter. Such a problem does not normally arise with UHF transmissions because the shorter wavelength means that the probability of finding almost full signal cancellation over a large area is much less.

10. CONCLUSIONS AND RECOMMENDATIONS

To date, the work carried out has shown that the BBC UHF prediction program (without any modification other than that necessary to allow operation at frequencies below 471 MHz) works reasonably well as a basic model for predicting both UHF and VHF mobile coverage in the London area. Earlier work had shown that predictions using the VHF program were less successful since, on average, they were some 15 dB above the measured field strength. This was due to differences in the way that diffraction and clutter loss are calculated, arising from the VHF program's original use as a maximum interference predictor in varying terrain clutter.

From the measurement work, four distinct types of clutter were identified (rural, sub-urban, urban and dense urban). Analysis of the measurements showed that, in areas characterised as dense urban and depending on frequency, the signal could be attenuated by up to 19 dB (mean value) relative to a rural area. The prediction program calculates clutter loss on the basis of Fresnel zone occupancy and was originally optimised for nominally sub-urban areas. No doubt it could be modified to include the effects of additional urban clutter but then the problem would be to identify the actual categories from topographical data.

Any further refinement of the program should involve examination of the way in which diffraction loss is determined. For instance it may be that certain calculations, such as the development of a wedge surface from a knife-edge, could well be omitted without impairing accuracy for these applications. However it must be remembered that any modifications of this type will require the program to be re-optimised on measured data. Certainly the program as it stands appears to be quite adequate for most mobile coverage assessments and, with a standard deviation in the range 5 to 9 dB, the results are as good as, and in some cases better than, those obtained by other published methods.

Nevertheless, these conclusions can only be considered provisional since they are based on a limited amount of data. Also they only apply to transmissions from a relatively low transmitting antenna height in a restricted range of terrain type.

Similar measurements need to be made on transmissions from a high site and in areas outside London for further comparison with predictions. It will then become apparent as to whether the UHF program can be used as it already stands for predicting mobile coverage in all conditions or whether more development is necessary.

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